SD
11
.R6

Timber Surveys

LIBRARY
PACIFIC NORTHWEST FOREST AND RANGE
EXPERIMENT STATION
PORTLAND, OREGON

Portland, Oregon

July 1, 1958

GUIDES FOR VARIABLE PLOT CRUISING IN REGION 6.

Prepared by the following Region 6 Forest Service personnel:

T. S. Kampmann, Forester, Division of Timber Management
Leo D. Caron, District Ranger, Okanogan National Forest
Kenneth R. Eversole, Forester, Willamette National Forest
Forrest W. Jones, Forester, Fremont National Forest
Marvin G. Perkins, Forestry Aide, Gifford Pinchot National Forest
Don Tandy, Forester, Snoqualmie National Forest

Property of
National FS Library
USDA Forest Service
240 W Prospect Rd
Fort Collins CO 80526

TABLE OF CONTENTS

	Page
Some Terms Used in Variable Plot Cruising	1-2
SUMMARY OF THE VARIABLE PLOT METHOD OF CRUISING	3
Brief History	3
Objectives in Using the Method	3
Advantages	4
Disadvantages	4
APPLICATION OF THE METHOD-PREFIELD CONSIDERATIONS	4
Determination of Sample Size (Number of Sample Points)	4
Sample Distribution	4
Determination of Basal Area Factor to Use	4-5
Kind of Sample	6-7
Checking Instrument For Basal Area Factor	7
Prism Calibration Procedure	7-9
Plot Cards	9
Other Equipment	9
Locating Sample Points	9
Figure 3 East Side Plot Card	10
Figure 4 West Side Plot Card	11
FIELD PROCEDURE - PREFIELD CONSIDERATIONS	12-15
DETERMINATION OF STEM AREA PER UNIT OF AREA	17
Basal Area (Stem Area) Determination	17
Variable Plot Cruising Instruments	17
Glass prisms	17
Angle gauges	18
Speigel-relaskop	18
Instrument Calibration	19
Basal Area Determination Procedure	20-21
MEASURED PLOTS	22
Frequency of Measured Sample Points	22
Procedure on Measured Sample Points	22
For trees intercepted by the angle	22
A. Obtain data needed for volume to stem area ratios	22
Obtain the diameter of the tree at the sighting point	22
Obtain height measurements for all trees intercepted by the angle	23
Record defect and log grade data in the usual manner	23
Obtain form class of trees as needed	23
Bark thickness ratios	23
Forked trees and abnormal trees	24
B. Quality determination	24
C. Other data	24
D. Techniques for special situations	24
1. Cull trees	24
2. Leaning trees	24
3. Down trees	25
4. Forked trees	25

TABLE OF CONTENTS -(Continued)

	Page
OFFICE PROCEDURES - VARIABLE PLOT METHOD	26-28
Basal Area	26
Volume Determination	26
Volume Computation	27
Quality Computations	27
Grade Computation	27
Log Stock Tables	28
THE FREMONT METHOD OF LOG STOCK TABLE COMPILATION	28
OTHER DATA	28
STATISTICAL ANALYSIS	28

APPENDIX

	Part
Equipment List	a
The Plot Radius Factor Method of Determining Diameter at the 16-Foot Point on a Tree	b
Methods of Determining Form Class Using Variable Plot Cruising Techniques	c
Decimal C Board Foot-Basal Area Ratio Tables by Girard Form Classes for 16-Foot Logs. For form classes 67 to 90, incl.	d
Board Foot-Basal Area Ratio Tables by Girard Form Classes (64, 66, 68, 70, 72, 74, 76, 78, 80, and 84) for 32-Foot Logs	e
Volume Table for Determining Volume in 16-Foot Logs When Sighting at 16-Feet	f
Volume Table for Determining Volume in 32-Foot Logs When Sighting at 16-Feet	g
Cruise Calculation Sheet for Variable Plot Cruises	h
The Frequency Method of Log Grade and Log Stock Table Compilation	i
Bibliography	j

Some Terms Used In Variable Plot Cruising.

angle cruising - see variable plot method.
angle gauge - any instrument used to project an angle in variable plot cruising including prisms, relaskops, Panama gauges, and other devices designed to project a given angle or angles.
angle gauge projection - observations when projecting an angle to determine the trees that are to be counted.
bark thickness ratio - the relationship of tree diameter inside the bark to tree diameter outside the bark usually expressed as a three-place decimal.
basal area - the cross-section area of a tree outside bark usually measured in square feet at d.b.h.; see stem area.
basal area factor - see stem area factor.
Bitterlich method - see variable plot method.
board foot-basal area ratio - see volume-stem area ratio.
boarderline tree - a tree whose sides are exactly tangent to the projected angle; a tree at maximum distance from the sampling point which just subtends the projected angle.
calibration - the stem area factor of given angle; the process of determining the stem area factor for a given angle or angle measuring device.
concentric plot method - see variable plot method.
count plots - sampling points at which intercepted trees are counted by species to determine average stem area per unit of area.
critical angle - the angle projected from a sampling point by any of the various instruments used for this purpose.
diopter, prism diopter - a measure of right angle displacement when sighting through and over a prism. One diopter equals a displacement of one unit per 100 units of distance.
frequency - the number of trees of a given diameter on a per acre basis determined by dividing the stem area factor by stem area of the tree of the given diameter.
grade plots - see measured plots.
half plot - see half point.
half point - the 180-degree segment around a sampling point generally the downhill portion from a line through the sampling point. Also called half plot.
measured plots - sample points on which intercepted trees are measured for diameter, height, defect, grade, or other items as the basis for stem-area ratio determination, log grade structure, defect deductions, and other desired data; also called grade plots.
multi-plot method - see variable plot method.
per acre conversion factor - the average tree count from all plots by species multiplied by the stem-area factor.
plotless cruising - see variable plot method.
plot radius factor - for a given critical angle, the distance per unit of tree diameter from the sampling point to a point at which the tree would be a borderline tree; plot radius factor times diameter is the maximum distance at which a tree would be counted; frequently used to determine whether borderline trees are in or out on steep ground or where observation is difficult because of brush or intervening obstructions.
point sampling - see variable plot method.
prism, plano prism - a precise optical instrument with two plane faces that are not parallel (for variable plot cruising the instrument ordinarily consists of wedge shaped precision ground glass). The instrument bends light rays resulting in displacement of objects sighted through and over the prism. Displacement is proportional to the angle between the wedge faces. Also called wedge.
prism cruising - see variable plot method.
prism factor - see basal area factor.

relaskop, Spiegel-relaskop - a hand instrument for measuring stem area, heights, tree diameters, distances, slopes, and angles with automatic corrections for slopes.

sample point tally - data recorded at either a measured plot or a count plot.

sampling point - the point from which a predetermined angle is projected to determine basal area (tree count) per unit of area; corresponds to plot center in conventional circular plot cruising.

slope correction - an adjustment of the critical angle to compensate for the effects of slope when observing stem area above or below a horizontal line of sight.

stem area - may be synonymous with basal area; usually refers to cross-section area of a tree either inside or outside the bark measured in square feet at some point above d.b.h. such as at 16 feet.

stem area factor - the stem area per unit of stand area for a given angle for each tree intercepted from a sampling point. Also called prism factor or basal area factor.

stem area ratio tables - may be synonymous with volume basal area ratio tables; the term is usually applied to the ratio between volume of the tree and stem area inside bark at some point above d.b.h. such as at 16 feet.

stem frequency - see frequency.

variable plot method - a system of cruising by which volume per unit of surface area is derived from average stem area per unit of surface area multiplied by the volume per unit of stem area. Also called Bitterlich method, plotless cruising, variable radius plot cruising, multi-plot method, concentric plot method, angle cruising, multi-plot method, point sampling.

variable radius plot cruising - see variable plot method.

volume-basal area ratio - see volume-stem area ratio.

volume-basal area ratio tables - tables showing volume per square foot of basal area outside bark derived by dividing the volume of a tree by basal area of the tree at d.b.h.; also called board foot-basal area ratio tables; see stem area ratio tables.

volume-stem area ratio - the volume per unit of stem area. Also called volume-basal area ratio or board foot-basal area ratio.

wedge - see prism. Any instrument used to project the angle in variable plot cruising is sometimes called a wedge.

wedge cruising - see variable plot method.

wood to d.o.b. ratio - same as bark thickness ratio.

SUMMARY OF THE VARIABLE PLOT METHOD OF CRUISING

The variable plot method of cruising is a system by which volume per acre is determined by multiplying basal area per acre by the volume per square foot of basal area. Basal area per acre is determined by projecting a predetermined angle from a number of sampling points and counting the trees intercepted by the angle. The average number of trees intercepted per point multiplied by a factor that applies to the angle used gives the basal area per acre.

The common procedure in this country is to determine stem area as square feet of basal area per acre. The volume (usually board feet or cords) represented by each square foot of basal area is determined. The basal area per acre multiplied by the volume per square foot of basal area equals the volume per acre. For example, if a stand has an average basal area of 80 square feet per acre and each square foot of basal area represents 200 board feet, the stand volume is 80 times 200 or 16,000 board feet per acre.

When an angle is projected from a sampling point, each tree intercepted by or equal to the angle represents an amount of stem area per acre (or other unit of area). The stem area represented by each tree intercepted is in proportion to the size of the angle projected. In other words, the larger the angle projected, the greater the stem area per acre for each tree intercepted. Why this is true and how it is calculated is explained in a later section.

The volume represented by each square foot of stem area is equal to the volume of the tree divided by the stem area of the tree. For example, if the volume of a tree is 900 board feet and the stem area is 2.50 square feet, the volume for each square foot of stem area is 900 divided by 2.50 or 360. This is called the stem area ratio (also frequently called the board foot-basal area ratio).

These are the basic aspects of the method in the most simple form. Additional procedures are applied to adjust for or to derive defect, ground slope, log grade data, tree form, bark thickness corrections, or other factors that are necessary to arrive at the desired results.

Brief History

Variable plot cruising provides a new concept in forest inventory procedures as used in the United States. This method, developed in Europe by Dr. Walter Bitterlich, was first publicized in 1948. Dr. Lewis R. Grosenbaugh of the U. S. Forest Service introduced the Bitterlich method into this country in 1952. Although the method is a radical departure from the customary methods, its use has increased at a rapid rate. Several organizations in the Pacific Northwest, as well as in other parts of the country, have adopted it as their standard method of cruising.

Methods of variable plot cruising suitable for use in the forests of the Pacific Northwest have been developed through the efforts of Lucien B. Alexander of Mason, Bruce and Girard, John W. Bell of the Oregon State Board of Forestry, and Norman Marsh of the Oregon State Tax Commission.

Objectives in Using the Method

The method provides a more economical determination of volume and value without sacrificing accuracy. It is simple to apply and tends to reduce technique error.

Ordinarily the method can be used in any situation where the usual cruising techniques might be applied.

Advantages

The above and other advantages of the system include:

1. Eliminates measurement of plot boundaries.
2. Greatly reduces number of diameter measurements required.
3. Reduces the average number of trees measured at each sampling point.
4. Both field and office production are increased. These may be doubled or more than doubled.
5. A better balanced sample of the various tree size and value classes is obtained.
6. By eliminating plot radius measurement and number of trees per sampling point adequate time is available for very careful examination of borderline trees, log grading, and defect determination.
7. Application is simple.
8. Accuracy is increased.
9. Preliminary checks indicate that the guide lines included in a later section, result in greater accuracy than is obtained with an equivalent number of 1/5th acre plots.

Disadvantages

1. Because the system is simple to apply, careless application may result.
2. Poor light conditions restrict or make application more difficult at times.
3. Initial explanation of basic principles is more complex.
4. When log grades by log size classes are required, log stock table data compilation introduces a few complications.

APPLICATION OF THE METHOD
PREFIELD CONSIDERATIONS

Determination of Sample Size (Number of Sample Points): The variable plot method does not involve any change in procedure for determining the size of the sample needed. For any given area the number of points to be sampled is determined in the same manner as in conventional fixed-radius plot cruising when using quarter acre or fifth acre plots. The frequency of measured sample points is covered in the section on measured plots.

Sample Distribution: Distribution of sample by the random versus the systematic method has been subject to much discussion. Statisticians are of the opinion, although it is difficult to support analytically, that the systematic sample gives the best results. Experience indicates that when a straight random sampling method is used the quality sample may not be as representative as that obtained with a systematic sample. This seems to be particularly true in the case of minor species. With the variable plot method, the quality sample obtained is normally based on fewer trees as compared with the sample derived from fixed-radius plot cruising. For this reason, the quality sample must be more truly representative. For the reasons noted above, the systematic method of sample distribution is recommended for the variable plot method.

Determination of Basal Area Factor To Use: The selection of the basal area factor to use for any given area is dependent upon upon the character of the stand to be sampled and is dependent upon a number of factors. However, a general rule of thumb is to select an instrument that will sample an average of four to eight

trees per sample point. This, of course, must be tempered with local experience and knowledge of stand conditions to insure that the sample is reasonable - i.e., in areas where only a limited number of cut trees per acre are encountered, such as four per acre, a sample point approximating one acre in size may not be feasible. Normally, the larger the timber, the larger the critical angle needed; the more scattered or small the timber, the smaller the critical angle.

Guidelines have been developed to assist in selecting a basal area factor to use. The application of these guidelines, as listed in the table below, is recommended until local experience develops more definite local guides. These should be used as guides rather than fixed rules.

Sawtimber Class	Average Stand Diameter	Approximate B.A. Factor	Approximate Corresponding Diopter
Douglas-fir Subregion			
Very large	Over 48"	55-70	7-8
Large	32"-48"	35-55	6-7
Medium	16"-30"	20-30	5
Small	6"-14"	10-20	3 or 4
Ponderosa Pine Subregion			
Large, uncut	over 36"	20-30	5
Average, uncut	30"-36"	15-20	4
Normal select cut	18"-30"	10-20	3 or 4
Heavy select cut	14"-18"	5-10	1-3
Lodgepole & other pole size stands	6"-12"	5-10	1-3

Usually, after the basal area factor has been selected for a given cruising project, only instruments with that factor should be used. In the case of prisms, (with exceptions to ground prisms) the basal area factor will rarely be exactly the same for each prism of a given diopter. The factors of ordinary prisms may vary from a few hundredths to several tenths, or even as much as one or two whole factors. Several prisms with slight variance of factors can be used on the same cruise. When this is done the basal area factors must be weighted with the correction being directly proportional to the difference between basal area factors used.

In some cases the use of two different basal area factors may be desirable, (i.e.- a two-storied stand containing poles and large sawtimber). When this is done the data obtained with each prism is to be compiled separately. This procedure is comparable to using two sizes of circular plots with common centers.

For information, the following are exact basal area factors for prisms ground to exact diopters:

Diopter	B.A.F.
1	1.0890
2	4.3556
3	9.7988
4	17.4170
5	27.2080
6	39.1691
7	53.2958
8	69.5847
9	88.030
10	108.628

Kind of Sample: The cruiser may measure the sample at d.b.h. as is normally done with the fixed-radius plot method, or he may sight some other point on the tree such as the top of the first 16-foot log. If the 16-foot method is used, an instrument with a lower basal area factor than that indicated by the guidelines may be desirable, because the reduced stem area at that point will usually lower the stem count per sampling point below the recommended standard of four to eight trees. The critical angle of an instrument with a lower basal area factor will compensate for this as illustrated in Figure 1.

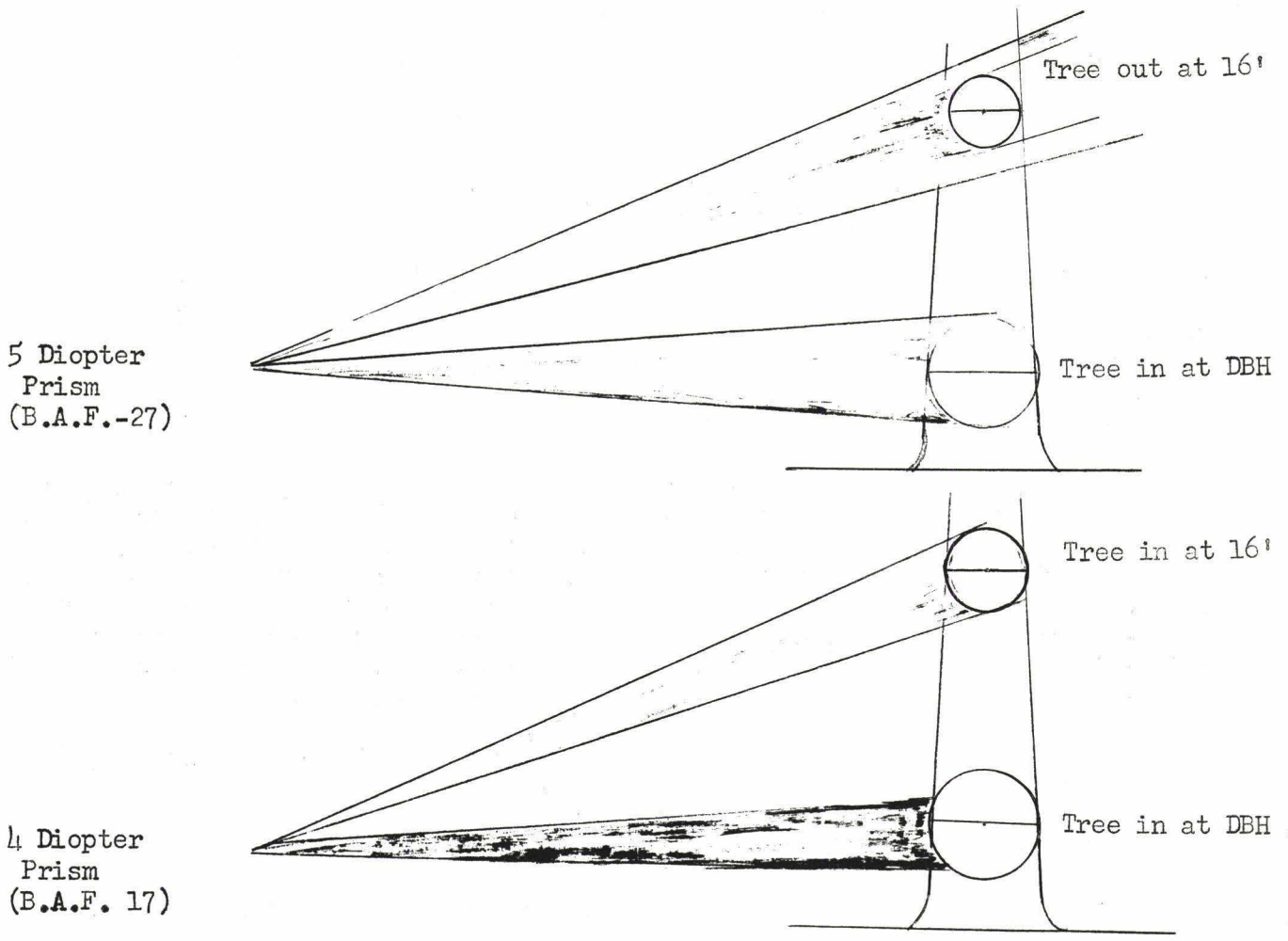


FIGURE 1 - Illustrating the reason for using an instrument with a lower B.A.F. when sampling at 16'.

The cruiser also has a choice of "full" or "half" sample points. The use of one or the other for any given stand or area should be decided in advance of the cruise to avoid mixing of two types of sample points. Both might be used in a cruising project if applied separately to different segments of the area. If this procedure is desirable, the data should be treated separately.

Full Sample Points - (360 degrees) are best for level to moderately steep terrain and in open stands.
Half Sample Points - (semi-circular) are best for areas of steep terrain. One of the advantages of this type of sample is the elimination of the problem of large vertical angles encountered in sighting uphill, especially when the sample is measured at 16 feet. (See Figure 2). It also has an advantage in areas of heavy brush or reproduction where sighting only downhill minimizes the chance for error that may result from difficulty in observing a lower point. Use of the half point usually requires an instrument with a lower basal area factor than that which might be used in the same area with the full sample point technique. If a lower factor is not used the resulting sample will be reduced enough to lower the accuracy of the cruise. The sampling area by half points should be approximately equivalent to that which would be obtained if full sample points were used.

Checking Instrument For Basal Area Factor: Instruments, either mechanical or optical, may be purchased that have exact factors. In the case of prisms ground to approximate diopters calibration is necessary to determine the exact basal area factor. Mechanical instruments, even though precision made, should be checked for accuracy. Since certain instruments are mechanical, they should be checked regularly to detect inaccuracies that may develop through minor mechanical failures.

Prism Calibration Procedure:

1. Prepare a square or rectangular target, preferably one foot in width, and place it at about table height on a truly vertical surface. (Check the surface for vertical accuracy and adjust the placement of the target accordingly.)

2. At a point which is on a line extending at exact right angles to the face of target set up and level a table with the center of the table at an approximate distance from the target as listed below:

Basal Area Factor	Prism Diopter	Approximate Distance in Feet to Target
5	1	104
	2	50
10	3	33
15		27
	4	25
20		23
25		21
	5	20
30		19
35		18
40	6	17
45		16
50		15
55	7	14
60		13
70	8	12

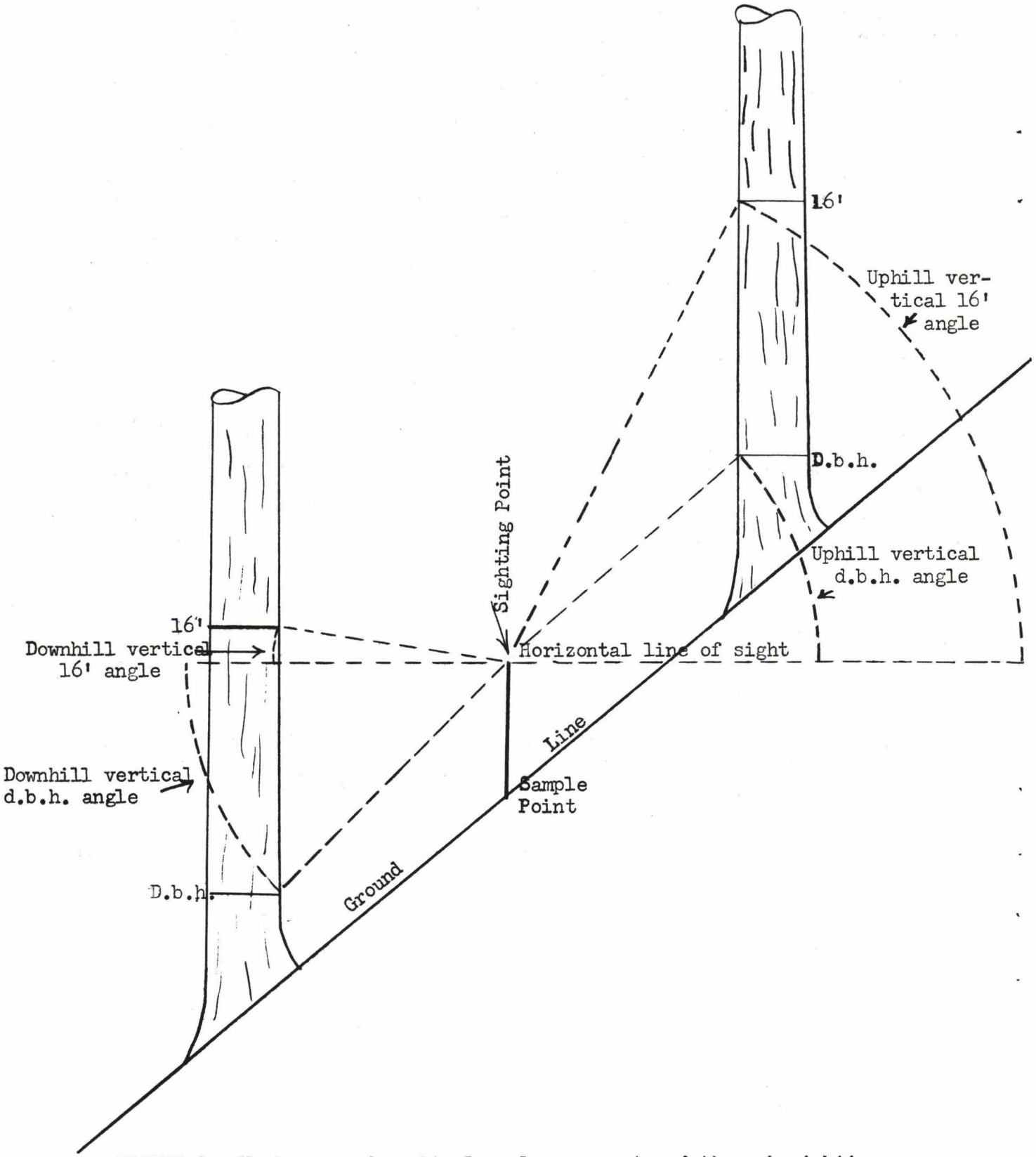


FIGURE 2 - Variances of vertical angles encountered through sighting uphill versus downhill sighting.

3. Tape a piece of paper on the center of the table top, and draw a line on the paper that is perpendicular to the target.

4. Set the instrument on the line at right angles to the line. It may be desirable to use a drafting machine to keep the instrument at a right angle to the line.

5. Sight through the instrument and, keeping it on the line, move it toward or away from the target until the target image is completely displaced or subtended. The target should be precisely aligned with the calibrations on mechanical instruments, and in the case of prisms, with the edge of the target as sighted over the prism. The position of the instrument is then marked on the paper. This step should be repeated at least six times to obtain an average measurement.

6. The average distance from the target center to the prism center or sighting point on mechanical instruments should be measured to the nearest 1/100 foot. The basal area factor is then computed as follows:

$$B.A.F. = 10890\left(\frac{w}{d}\right)^2$$

When d = distance from instrument to target
w = width of target in feet
Example: When d = 23.25 feet
w = 1.0 feet

$$B.A.F. = 10890\left(\frac{1.0}{23.25}\right)^2$$
$$= 10890\ (.00185)$$
$$= 20.146$$

7. The calibrated basal area factor should be marked on the instrument. This may be done by typing the factor on a small piece of paper and then attaching it to the instrument; or, it may be marked on the instrument with India ink. With either method, fingernail polish or plastic should be used as a seal. Another method for prisms is to scratch the factor on one corner of the face of the prism.

Plot Cards: Plot cards have been developed for east side and west side use. Samples of these two cards are shown in Figures 3 and 4.

Other Equipment: A checklist of equipment and material that may be of value to the cruiser is listed in the appendix, part a.

Locating Sample Points: Location of sample points on the ground is accomplished in the same manner as in conventional fixed-radius plot cruising.

FRONT

SAMPLE POINT TALLY

Cutting Unit ___ Basal Area Factor_____

Estimator _____ Date _____

	SPECIES								
1									
	Stand Improvement	Low	Med.	High					
	Pruning								
	Thinning								
	Planting								

T.___ R.___
Sec. ___
Plot No. ___
Coord- ___N
inate ___S
Stand Class.
_____Ov.St.
Un. St

	SPECIES								
2									
	Stand Improvement	Low	Med.	High					
	Pruning								
	Thinning								
	Planting								

T.___ R.___
Sec. ___
Plot No.___
Coord-___N
inate ___W
Stand Class.
_____Ov.St.
Un.St.

	SPECIES								
3									
	Stand Improvement	Low	Med.	High					
	Pruning								
	Thinning								
	Planting								

T.___ R.___
Sec.____
Plot No.____
Coord-___N
inate ___W
Stand Class.
_____Ov.St.
Un.St.

	SPECIES								
4									
	Stand Improvement	Low	Med.	High					
	Pruning								
	Thinning								
	Planting								

T.___ R.___
Sec. _____
Plot No._____
Coord-___N
inate ___W
Stand Class.
_____Ov.St.
Un.St

INSTRUCTIONS FOR USE OF TALLY SHEET

Cutting Unit - It may be desirable to divide the proposed sale or cruising area into sampling units, these may be numbered numerically and keyed to a work map.

Species - Normally tally on a cruise for a sale will be only for those "cut" trees which meet minimum merchantability standards. If it is desirable to tally "leave" trees they may be so designated such as P.P.-L, W.F.-L, etc.

Stand Improvement - For purpose of classifying work to be done for pruning, thinning and planting standards may be set up for low, medium and high.

Plot Number or Coordinates - This provides a convenient method of indicating plot locations.

Stand Class - This provides a means of classifying a stand condition at or in the immediate vicinity of a sampling point. For example we may have $\frac{Plp,wf}{WFlwf,p}$ in which case we would have an overstory of large sawtimber which is predominately ponderosa over an understory of seedlings and saplings which are predominately white fir.

Note: At the bottom of the block is a space which may be used for other remarks or items such as the type of cutting which may be employed at a given point such as Release Cut, Improvement Cut, et.

Figure 3a - Preliminary draft of east side variable plot tally card (front).

BACK

Volume and Quality Data

T.__ ,R.__ Sec.____ Plot No._____

Coordinates _____ N. _____ W.

Sp.	Basal Area	Dia.	Ht.	F.C.	Percent Sound	Volume		log grades by position* 1 2 3 4 5 6 7 8 9 10 / 11 12 13 14 15 16
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	
							D	
							G	

* Two lines for trees with more than ten logs

INSTRUCTIONS FOR USE OF THE TALLY SHEET

This tally sheet is designed for use in prism cruising. Volume and quality may be taken once in each series of plots. This may be on each fourth sampling point or any other frequency desired and should be selected in an unbiased manner. The plot number or coordinate will correspond to one of the plots on the front of the tally sheet.

Basal Area - for each tree will correspond to the cross section area at d.b.h. of the tree.

Percent Sound - This may allow for an estimated amount of breakage and defect to fit the tree and ground conditions.

Log Grades - Line marked "g" is for grade. Line marked "d" is for log diameters. Diameters may be obtained from appropriate taper tables.

Figure 3b - Preliminary draft of east side variable plot tally card (back).

WEST SIDE PRE-SALE
CRUISE PLOT CARD

(1) Plot Number xxx_____ T._____ R._____ SEC._____

(4) Unit or type xx_____ Sample_____ or Coordinate-Chains N._____ W._____

(6) Forest xx_____ Cruiser_____ Compassman_____

(8) Working Circle x_____ Date_____

(9) Ranger District xx_____ Other Data Plot size

(11) Sale No. xx_____ B.A.F.

(13-14) Species	(15-17) 2-inch DBH Class	(18-19) Total Log Ht.	(20-21) Form Class	(22-23) Hidden Defect in %	(24-33) Log Grade by 32' Log Position 1 (24-25)	2 (26-27)	3 (28-29)	4 (30)	5 (31)	6 (32)	7 (33)
xx	xxx	xx	xx	xx	x x	x x	x x	x	x	x	x

FIELD PROCEDURES

PROCEDURE AT COUNTED SAMPLE POINT

1. Once the sample point has been determined and located, all observations should be taken directly over this point (with exception in cases of obscured trees). This requirement cannot be overemphasized. Erroneously including or excluding border-line trees can very materially affect results. (Figure 5 illustrates this point.) Using a staff will assure that all observations are taken over the center point. Some instruments are fitted with a holder or adapter to permit mounting on a staff. Simple holders and adapters can be made for prisms. Some instruments developed for slope correction when using prisms have incorporated mounting devices.

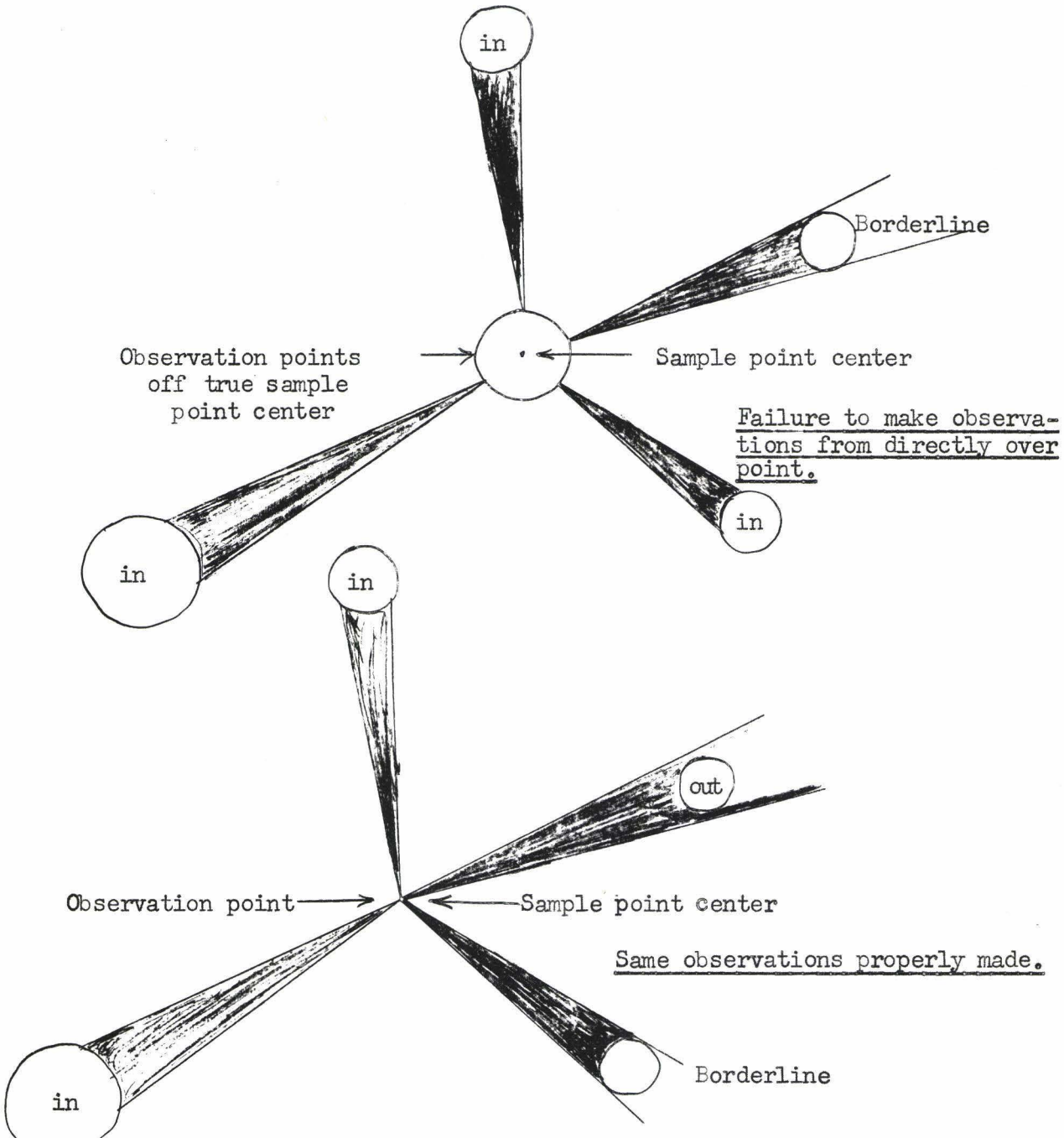


FIGURE 5 - Illustrating inaccuracies that can result from failure to make all observations from directly over the center of the sample point.

2. If "half plots" are used, they are established in the following manner:
   (1) The sampling point is determined in the usual manner.
   (2) A straight line is then projected through the sampling point approximately on contour with that point. This line is referenced through a tree, a stake, or other object. Care must be used to avoid bias in excluding or including trees when establishing the line on the contour.
   (3) All trees that lie on the downhill side of the projected line are now potential sample trees. No observations are taken above this line (observations are made on a 180-degree segment of a circle).

3. On either full or half plots observations are now made from directly over the established sampling point by use of one of the instruments previously discussed. With any of the instruments the procedure simply involves projection of predetermined angle, the size of which depends upon the basal area factor used.

   With instruments that have the critical angle fixed by means of markings only with those trees that equal or exceed the width of the markings as projected are recorded on the plot card. Figure 6 illustrates this point. When a prism is used only those trees that are displaced, the diameter of the tree or less are to be recorded. This is illustrated in Figure 7. If, after precise observation, a tree is determined to be exactly a borderline tree, it should be recorded as a half tree (.5 of a tree).

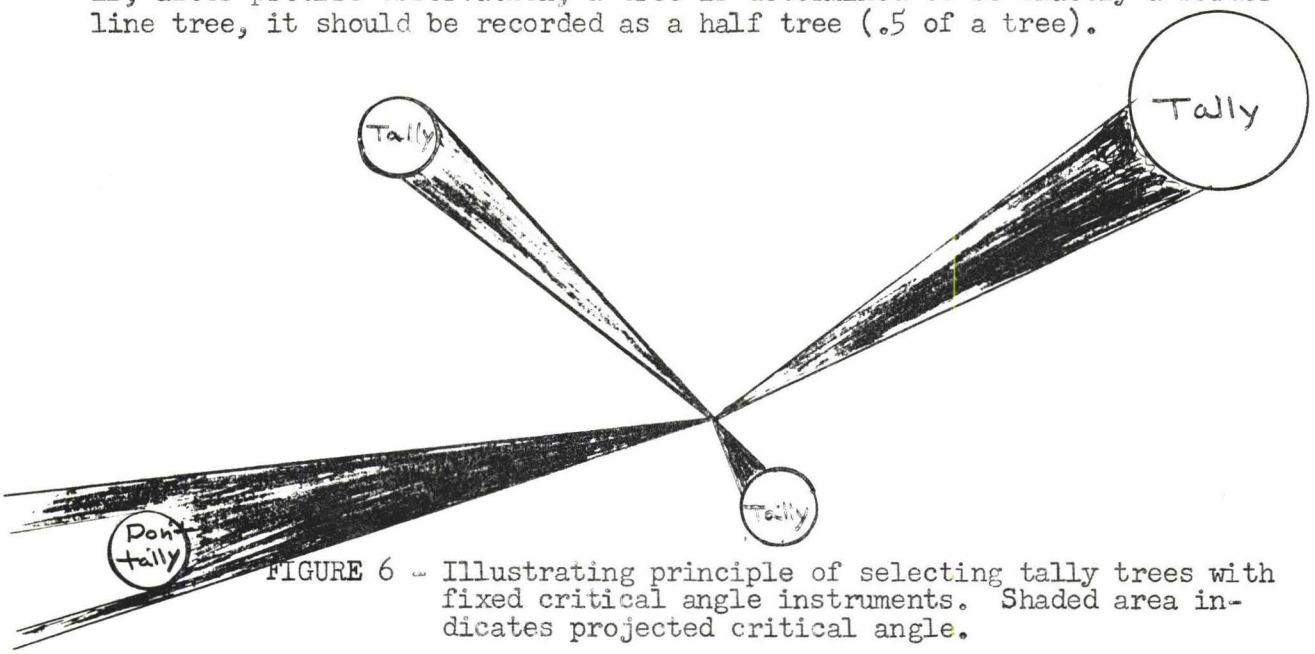


FIGURE 6 - Illustrating principle of selecting tally trees with fixed critical angle instruments. Shaded area indicates projected critical angle.

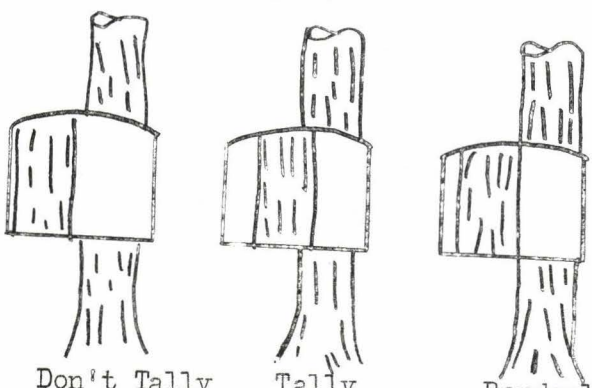


FIGURE 7 - Illustrating principle of selecting tally trees with a prism.

4. If a stem is obscured by intervening trees or brush it is permissible to move from the established sample point to a position from which the tree can be observed; however, it is essential that the same distance from sampling point to the tree be maintained. This is illustrated in Figure 8. Sometimes it may be found necessary to remove brush from the line of sight to accurately observe such trees, particularly if they are borderline trees. The distance may also be determined by direct measurement.

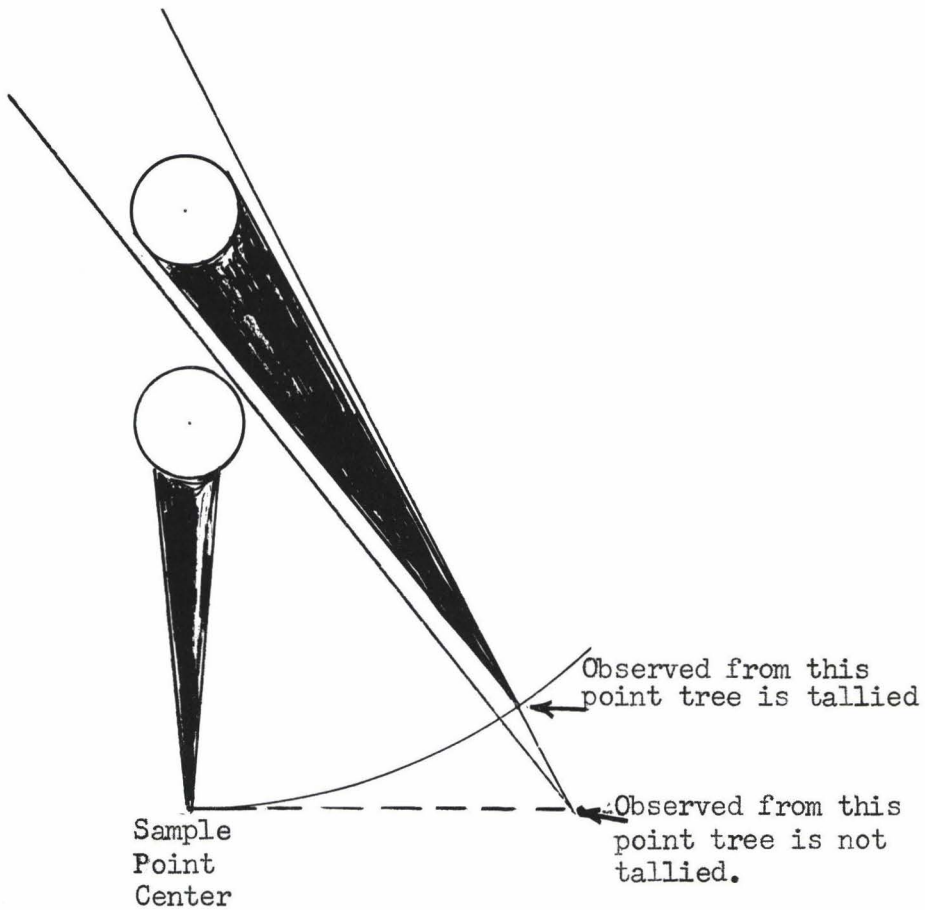


Figure 8 - Illustrating both correct and incorrect location for observing obscured tree. Solid line indicates correct line of travel to establish another point for observing obscured tree. Dashed line is incorrect.

5. Slope must be taken into consideration with the variable plot method to insure accuracy. Where slopes exceed 10%, it is necessary to make adjustments. Some mechanical instruments such as the Spiegel-Relaskop automatically adjust for slope. Other instruments may require slope adjustments. This can be accomplished by the use of several devices - some of which are illustrated in Figures 9, 10, 11 and 12. The adjustment necessary requires that the prism be rotated around the line of sight by exactly the angle of inclination of the slope. Figure 9 illustrates the use of the abney level to accomplish this correction. The procedure involves reading and setting the vertical angle of the slope on the abney level scale; placing the prism on the upper edge of the abney barrel, and then, keeping the bubble level, rotating the abney and prism at right angles to the line of sight and making the observations through the tilted prism. The prism may be fastened to the abney by means of a simple clip to facilitate ease in handling and reading.

A Finnish product, the clinometer, is illustrated in Figure 10. Slope adjustments with this device are made in a manner similar to that with the abney.

Two wedge prism slope-correcting devices have been designed by Forest Service personnel. The instrument in Figure 11 consists of a level and prism built into a plastic frame. It has a ball and socket joint and adapter, which permits the instrument to rotate when attached to the top of a staff. The vertical angle is determined by sighting along the top of the adjustment to the point being observed. The instrument is then turned 90 degrees keeping the same vertical angle as measured. The observation is then made through the tilted prism in the usual manner.

Figure 12 shows an instrument that incorporates an abney type level tube with percent and degree arcs. The prism is inserted in the top of instrument and may be secured by means of two set screws on the side. It also has a 1/4-inch hole in the base for attaching to a Jacob Staff ball and socket. Slope adjustments are made in the same manner as with the instrument discussed above. This instrument is sturdy, being constructed of wood, and permits interchanging of prisms.

A simple method for slope adjustment that involves no special device is to hold the prism perpendicular to the target, sight along the top of the prism to the observation point on the stem being sampled and at the same time, tilt the prism until it is parallel with the line of sight. The prism is them rotated 90 degrees, maintaining the angle determined and the sampling completed in the usual manner. This method is subject to some chance for error and its use is questioned but may be used if done with care.

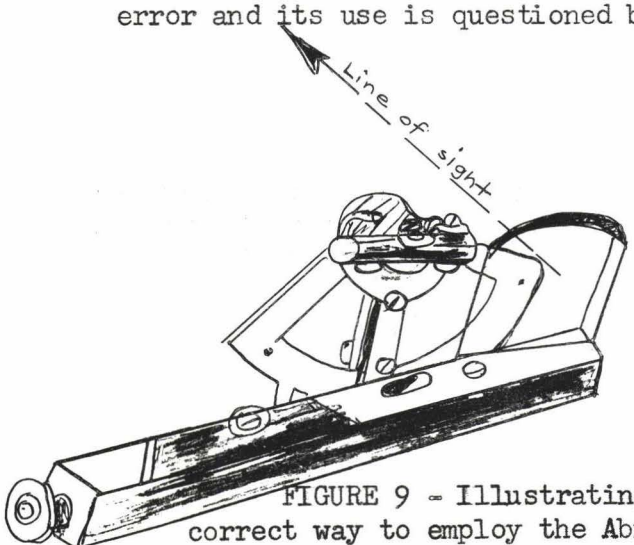


FIGURE 9 - Illustrating the correct way to employ the Abney and the prism for slope correction.

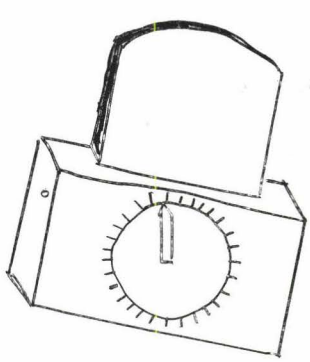
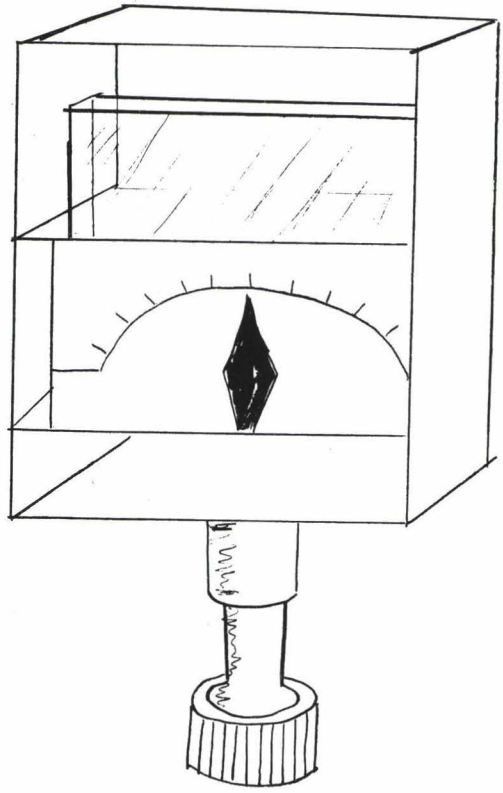


FIGURE 10 - Using a clinometer for slope correction.

FIGURE 11 -

Wedge - Prism - Level
Developed by R. J. DeWitz



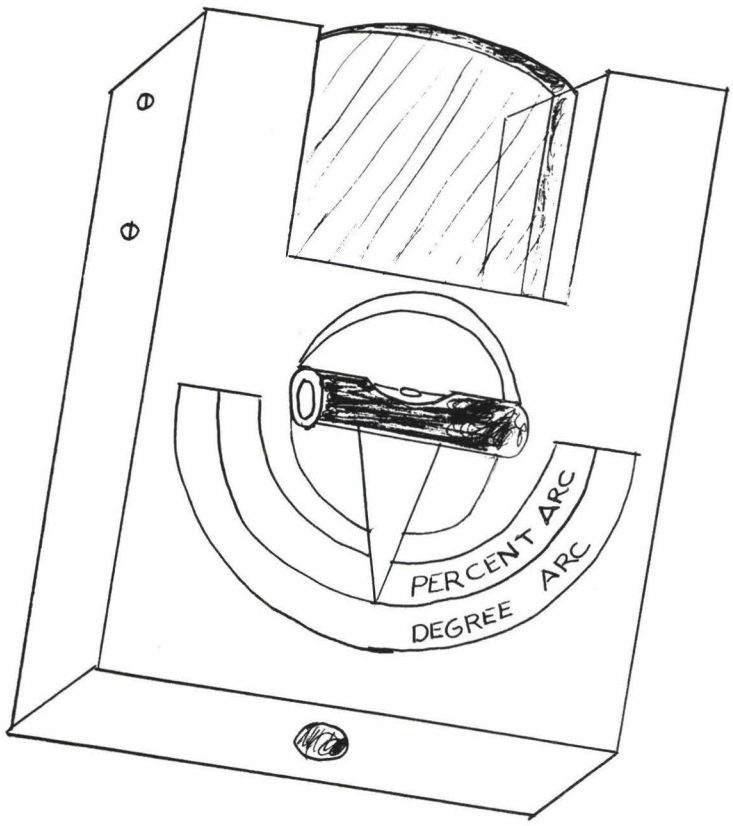


FIGURE 12 -

Wedge prism level
developed by
F. W. Jones &
W. C. Knechtel

DETERMINATION OF STEM AREA PER UNIT OF AREA

Basal Area (Stem Area) Determination

Timber volume determination, whether it be on a per acre basis or expanded to include an entire sale area, is dependent upon two factors: the basal area of the timber stand and the number of board feet which each unit of basal area (boardfoot-basal area ratio) represents. This section covers the determination of the basal or stem area of a timber stand.

The basal area per unit of area is dependent on two variables:

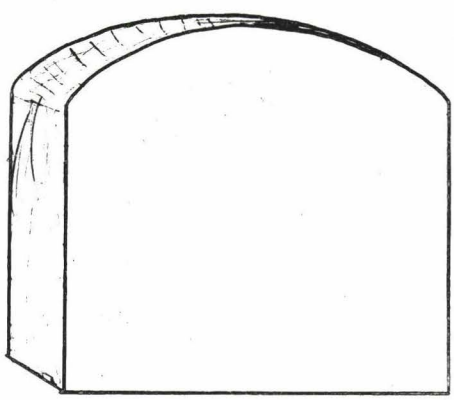
1. Stem diameter
2. Stem frequency

Numerous methods have been employed to determine timber volumes. The most common has been to measure the trees on plots or samples of a definite size and projecting the results to the area for which volume was required. Volume determination under such systems required many measurements of individual trees and sample areas and was very time consuming. The variable plot cruising procedure reduces the number of plot radius and tree diameter measurements to a minimum while maintaining the desired accuracy.

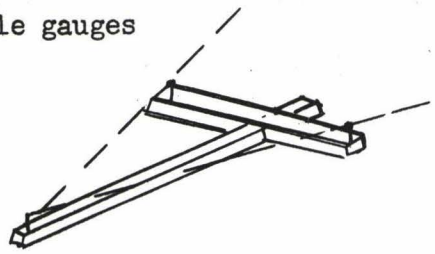
Variable Plot Cruising Instruments

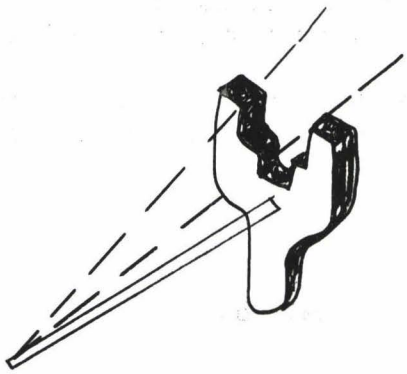
The primary purpose of any instrument used in variable plot cruising is to project an angle from the sampling point. Several major types of instruments have been devised and are currently being used in Region 6. They are the following:

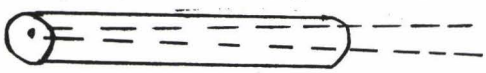
1. Glass prisms.



2. Angle gauges



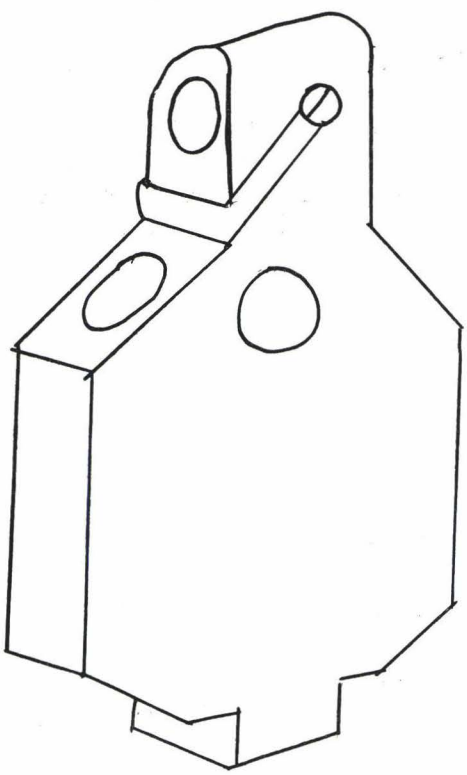




Panama Angle Gauge

End View

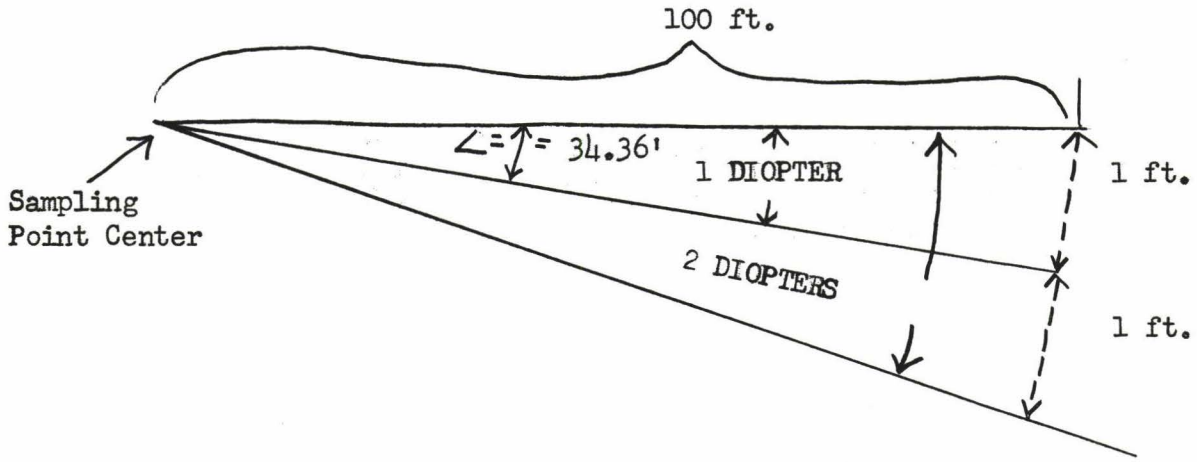
3. Speigel-Relaskop



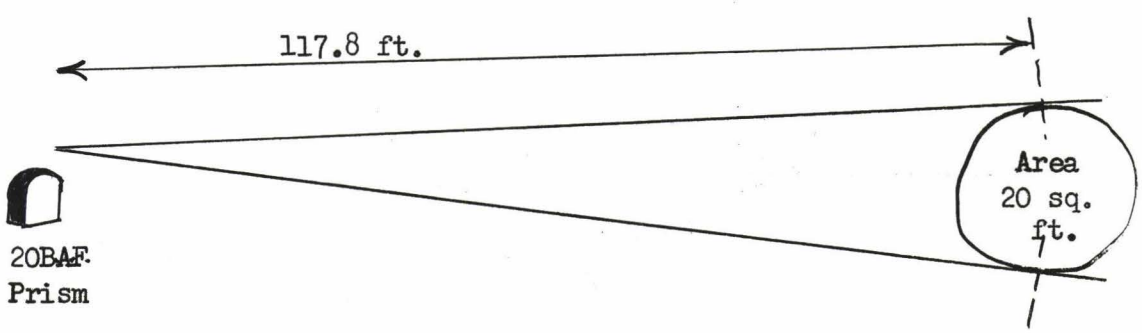
Instrument Calibration

All of these instruments project an angle from the sampling point center. The angle is selected to meet stem size and the stand density requirements.

The projected angle may be expressed in diopters. One diopter equals 34.36 minutes of angle or a displacement of one foot for each 100 feet of horizontal distance.



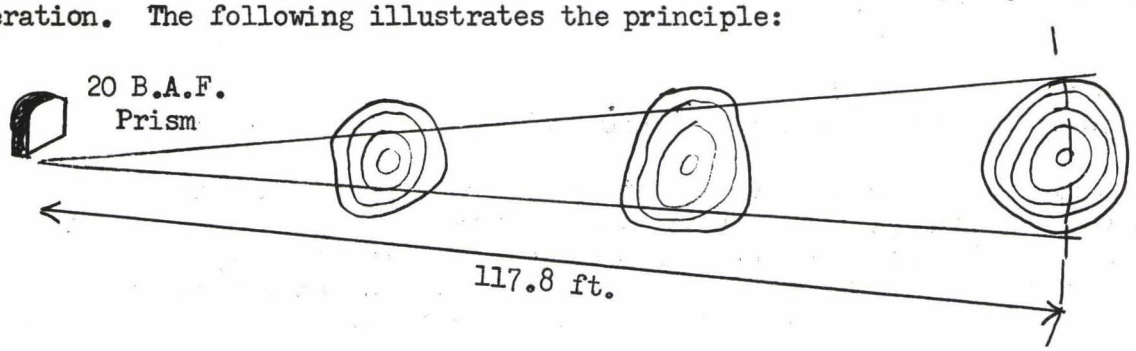
Prisms and angle gauges designed to measure units of basal area or actual angles rather than diopters are more commonly used. However, the principle is the same whether expressed as diopter or other units. In principle a definite angle is projected. For example, the angle of an instrument with a twenty-basal area factor exactly subtends the circumference of a tree whose stem area is twenty square feet and is located on the boundary of a one-acre plot (117.8 ft.).



Measured in diopters this instrument would be between a four and a five diopter.

Basal Area Determination Procedure

The above diagram illustrates that if the sample tree were the only tree present on the one-acre plot, the stem area per acre measured by the instrument would be twenty square feet. However, if there were additional trees at an equal distance from or closer to the sampling point and of the same size the stem frequency becomes a consideration. The following illustrates the principle:

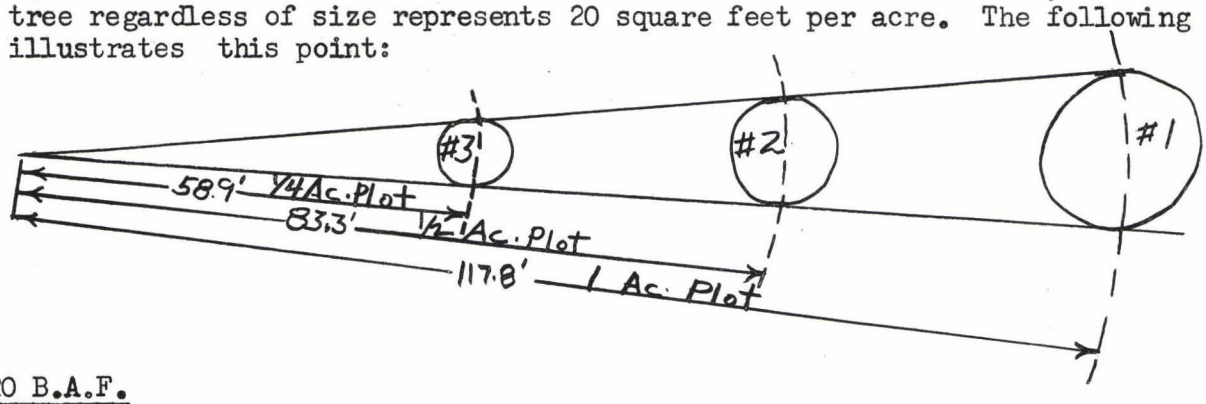


Because the additional trees are equal to or larger than the projected angle they contribute to stem frequency, and the stem area per acre is calculated as follows:

Stem area per acre = stem frequency X B.A.F. of the instrument
" " " " = 3 X 20
" " " " = 60 sq. ft. per acre

The trees used in the example are of equal size and in their various locations are far larger than need be, since a tree to be counted has only to touch the sides of the angles.

However, present in the stand are stems of various diameters which do not have an area of twenty square feet. The percentage of stem area of these trees in relation to a twenty square foot tree is exactly equal to the percentage that the area on which they are sampled is in relation to one acre. As an example, a stem with ten square feet of area could be no further from sample point than 83.3 feet or the radius of a one-half acre plot. When sampling area is considered, this tree whose stem area is ten square feet (or 50% of the tree whose stem area is twenty square feet) is a sample on a one-half acre plot. When the stem area is increased to a per acre basis, it will equal 20 square feet (stem area x converting factor*). Therefore, each counted tree regardless of size represents 20 square feet per acre. The following diagram illustrates this point:



Prism 20 B.A.F.

	Stem Area	Sampling Area	Converting Factor		Stem Area Per Acre
#1	20 sq. ft.	1 acre	1	=	20 sq. ft.
#2	10 sq. ft.	$\frac{1}{2}$ "	2	=	20 sq. ft.
#3	5 sq. ft.	$\frac{1}{4}$ "	4	=	20 sq. ft.

*Converting factor equals = $\frac{\text{1 acre}}{\text{Sampled area}}$

The basal area factor of an instrument can be calculated by either of two mathematical formulas prior to its use in the field as follows:

$$B.A.F. = \frac{43,560}{1 + 4\left(\frac{d}{w}\right)^2} \qquad \text{or} \qquad \left(\frac{w}{d}\right)^2 \quad X \quad 10,890$$

Note: d and w are in feet.
This calibration procedure has been outlined in a previous section.

In summary, stem area per acre is dependent on two variables: stem diameter and stem frequency. By projecting an angle which intercepts only trees of predetermined stem areas and counting only the intercepted trees, the stem area per acre can be determined. To insure that the projected angle is constant, instruments such as glass prisms, angle gauges and the Speigel-relskop are used.

MEASURED PLOTS

As stated previously the volume on a per acre basis equals: average tree count per sample point times basal area factor times average ratio of volume per square foot of stem area. Data taken on "measured" sample points furnishes the necessary data for (1) the determination of the average ratio of volume per square foot of stem area, (2) defect information and (3) log gradeinformation for the computation of the average selling values. The ratio of volume per square foot of stem area is obtained by dividing tree volume by the cross section area in square feet of the tree's stem. The stem area may be observed either at d.b.h. or at the top of the first 16-foot log. When sighting at the top of the 16-foot log the ratio is based on stem area inside the bark at 16 feet. When sighting at d.b.h. the stem area is determined outside the bark at d.b.h. When stem area is observed at d.b.h., stem area ratios may be taken from the basal area ratio tables compiled by Leo D. Caron, based on "Mason, Bruce and Girard's Form Class Volume Tables (Scribner Decimal C) for 16-foot logs," or similar tables for 32-foot logs compiled by the Gifford Pinchot National Forest. These are available from the Regional Office. When top of the first 16-foot log is observed, the following tables may be used:

Eastside - From J. R. Dilworth's book on Variable Plot Cruising, page 218.
Westside - From J. R. Dilworth's book on Variable Plot Cruising, page 219.
A copy of each of these is included in the appendix.

FREQUENCY OF MEASURED SAMPLE POINTS

The frequency or number of measured points is controlled by the sampling accuracy desired and the total number of sampling points. In general, the objective is to obtain a minimum of 60 measured trees of each major species to secure an adequate sample for stem area ratio determination. Normally, one measured sample point in four is judged to be adequate for an accurate determination of average ratios.

Further study is necessary to determine whether this will also give an adequate quality sample. Undoubtedly, it is an absolute mimimum for quality sampling. For minor species, knowledge of stand composition may indicate that volume and grade data must be taken at more frequent intervals. For very minor species, volume and grade data may have to be taken for all trees intercepted on all plots. In taking measurements and quality, trees must meet the minimum merchantability standards or be recorded as unmerchantable or cull trees.

PROCEDURE ON MEASURED SAMPLE POINTS

For trees intercepted by the angle:

A. Obtain data needed for volume to stem area ratios.

I. Obtain the diameter of the tree at the sighting point.

a. For tree sighted at d.b.h. the diameter is outside the bark at breast high. Diameters of all trees are obtained by use of diameter tape or cruiser stick.

b. For trees sighted at the top of the first 16-foot log the diameter is outside the bark and corrected to diameter inside the bark by application of the bark thickness ratio. The diameter at the top of the 16-foot log may be obtained by one of the following methods:

b.-1) By multiplying the tree d.b.h. by the 16-foot form class (inside bark form class)..

b.-2) By multiplying d.b.h. by form class (outside bark form class) and applying the bark thickness ratio.

b.-3) Plot radius factor method--since a prism is an accurate optical instrument the diameter of a tree at the 16-foot level can be measured by employing the plot radius factor. Using this procedure tree diameter and form class can be disregarded. The field procedure for this method is included in the appendix, part b.

II. Obtain height measurements for all trees intercepted by the angle.
In areas where trees are measured in terms of 32-foot logs, heights are taken to the nearest 1/2 log. For cruises which measure heights in terms of 16-foot logs, heights are taken to the nearest whole log.

III. Record defect and log grade data in the usual manner.
Cull or missing logs are recorded by log position. Log grades are recorded by log position.

IV. Obtain form class of trees as needed.
Methods of determining form class are included in the appendix, part c. When sighting at the 16-foot point, it is not necessary to obtain form class except as it may be used to determine the diameter at the top of the 16-foot log.

V. Bark thickness ratios.

Preliminary Bark Thickness Ratios
From studies of bark thickness there is surprising consistency in the proportion of the total diameter that is wood. These ratio of wood to total diameter figures for the top of the first 16-foot log have been found to be about as follows:

	General Average	Range in Averages	Special Problems
Douglas-fir	.901	.889 - .912	Ratio decreases toward ground. No sample for young trees.
Ponderosa pine	.906	.900 - .919	Changes with tree height.
Amabilis fir	.939	.937 - .942	
Hemlock	.944	.941 - .948	
Western red cedar	.951	.948 - .954	
Sitka spruce	.962	.955 - .971	
Western larch	.900	Unknown	Insufficient sample
Concolor fir	.897	.895 - .899	Varies with age.
Sugar pine	.883	Unknown	Insufficient sample
Incense cedar	.836	Unknown	Insufficient sample

Studies indicate that bark thickness as measured at DBH cannot be used to correct diameters at 18' above the ground. Neither can bark thickness ratios measured at 18' above the ground be applied to the top of the first 32' log.

These are guides only. Local measurements must be taken to use for local cruises. For example, local averages for old growth Douglas-fir have ranged from a low of .870 near Snoqualmie, Washington, to as high as .947 in the Rogue River area. With a basal area factor of 40, intercepting an average of 5 trees per point, would indicate a stem area of 200 square feet per acre outside bark. Correcting for bark thickness, stem area per acre inside bark would become 200 x $(.870)^2$ or 151.38 square feet to 200 x $(.947)^2$ or 179.36 square feet. If the general ratio of .901 was used, stem area per acre inside bark would become 200 x $(.901)^2$ or 162.36 square feet.

Assuming the correct bark thickness ratio to be either .870 or .947, the stem area inside bark (and also volume) would be either 7.25% too high or 9.48% too low, respectively. Stated another way, if the board foot basal area ratio was 500, use of the general bark thickness ratio would indicate a stand of 81,180 board feet per acre. The .870 ratio would result in a stand of 75,690 board feet and the .947 ratio in a stand of 89,680 board feet. Volume per acre would be either 5,490 board feet too high or 8,500 board feet too low.

The use of substantiated local bark thickness ratios for each cruise cannot be over-emphasized.

VI. Forked trees and abnormal trees
Trees will be measured and log graded on the same basis as they are counted on the "count" plots. This applies to down, cull, or leaning trees.

B. Quality determination
Quality data is normally taken for each tree which has been measured for diameters and heights. Cull or missing logs are indicated by position in the tree.

C. Other data
Data in addition to the tree measurements and log grades of trees may be collected to meet local requirements. This may include data on snags, cull trees, "leave trees", pole stand, etc.

D. Techniques for special situations.

1. Cull trees
Ordinarily cull trees are included with the total tree count by species from all sample points. The sample for cull trees must then be a part of the data taken on the measured point. A cull tree would have a basal area ratio of 0. If cull trees are not included in the total tree count, every tree intercepted on all plots must be critically examined as to whether or not it is a cull. This could be very time-consuming in highly defective stands. Necessity for close examination ov every tree would lose much of the advantage of the variable plot method.

2. Leaning trees
In order to determine whether a tree which leans to right or left of the line of sight is in the plot, rotate the angle measuring device until it is at right angles to the center line of the tree. Slope correction may require a further adjustment. Trees leaning toward or away from the line of sight should be considered "in" or "out" as intercepted, based on the probability that as many trees lean toward plot center as lean away from plot center.

3. Down trees

Hold the angle device at right angles to the stem at the point of interception. If the interception point is obscured, move the viewing instrument to another location, keeping the same relative distance. Another method is to use the plot radius factor as discussed previously.

Another method is to have one man hold a stick with a length equal to the log diameter in a horizontal position directly over the point of interception. Observing the length of the stick through the angle device would then determine whether the down tree was "in" the plot. For down trees the point of observation (d.b.h. or diameter at 16-feet) as the tree lies would determine whether the windfall was "in" regardless of original stump location. This is based on the probability that the observation points of trees falling or sliding out of plots will equal the number falling into plots.

4. Forked trees

If forked above the first 16-foot log the tree should be treated as a single tree. If forked below the top of the first 16-foot log, each fork should be observed at a point equivalent to d.b.h. or 16 feet on the fork and tallied as individual trees.

OFFICE PROCEDURES - - VARIABLE PLOT METHOD

The cruise compilations are done in three steps. If basal area and volume only are needed, the calculations are quite simple. Quality computations are somewhat more complex. This is especially true for end product appraisals where log stock tables are required. In the latter case hand compilation is feasible, but electronic computation is most efficient. To avoid errors in handling weighted data, carefully thought out procedures must be followed. Any deviations from the following procedures should be carefully checked for accuracy.

Basal Area: Basal area per acre by species is a basic figure necessary for volume computations. It may be used directly in many ways, i.e., percentage of cut and leave in thinnings, cost of snag falling, and determining stand normality. Average basal area per acre is calculated as follows:

1. Total trees counted (by species) on all plots divided by the number of sample points equals average count per sample point.

2. Average count per sample point (by species) multiplied by the basal area factor equals basal area per acre (by species).

Usually only one basal area factor is used in sampling a given population. If more than one factor is used, these should be weighted. If half-points are used the basal area factor should be doubled. If the 16-foot sighting point is used the basal area per acre outside the bark must be converted to stem area inside the bark. This is done by multiplying the basal area outside the bark by the square of the bark thickness ratio.

Volume Determination: Volume and basal area are very closely correlated. The variable plot method makes use of this correlation to convert basal area per acre to volume per acre. The volume in board feet per square foot of basal area is determined and applied as follows:

1. Appropriate volume - basal area ratio tables are used to derive gross ratios for each tree measured. Ratios are seldom computed by individual sampling points. Ratios are calculated separately for each species.

2. Log position percentage tables are applied to the gross ratio to get woods net ratio for each tree. Cull trees have a zero ratio and should be included in deriving the net ratio.

3. The average volume-basal area ratio is the sum of the woods net ratios divided by the number of trees contributing to the sum of the ratios.

4. The average basal area per acre multiplied by the average volume-basal area ratio equals average woods net volume per acre.

5. Hidden defect and breakage deductions are made in the usual manner to get net volumes per acre. Hidden defect and breakage factors may also be applied directly to the woods net average ratio.

6. Total volume equals net volume per acre times total acreage.

The following short computation illustrates the principle of deriving volume:

Volume Computation

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Species	No. Trees	No. Points	No. Count	B.A. Factor	B.A. per Acre	BF/BA Ratio	Wds. Net Per Acre	Per cent B&D	Net Vol. Per Acre
DF	190	38	5.0	40.00	200.0	168	33.6 M	15	28.6M
WH	76	38	2.0	40.00	80.0	140	11.2 M	15	9.5M
								Total	38.1M

1. (4) = (2) + (3)
2. (6) = (4) x (5)
3. (7) = Total woods net ratio + no. trees measured
4. (8) = (6) x (7)
5. (10) = (8) x (100 - (9))
6. (10) x Total acres = total net volume

A volume calculation form suitable for both east-side and west-side using either d.b.h. or the 16-foot sighting has been devised by Forrest Jones of the Fremont National Forest. Its use and advantages are included in the appendix, part h.

Quality Computations: Since the chance of a tree being included in the sample point tally is directly proportional to its basal area, proportionately more large trees are included in the sample. Such data as log grade information must be reduced to a unit-area basis. The simplest method uses the volume-basal area ratios:

1. The gross ratio for each tree measured is prorated to the logs comprising the several log grades and cull logs by the use of a log position percentage table. These values may then be handled as if they were volumes.

2. The proportions of the prorated gross ratio and cull logs, if any, for each tree are entered in a tabulation under appropriate grades. The totals in each grade are then divided by the sum of woods net ratios for all logs in the sample. From this the percent of volume in each log grade is computed.

The following is a short, simple illustration of log grade data compilation:

Grade Computation

D.b.h.	Tree Ht.	Grade by logs 1	2	3	Log Grades 3P	2S	3S	Cull	BF/BA Ratios
14	1	3S					103		103
22	2	2S	3S			119	40		159
38	3	3P	2S	3S	136	90	46		272
42	3	cull	2S	3S		90	47	137	274
								137	808 Gross:
								-	137
		Sum of the woods net ratios			136	299	236	=	671
		Log grades by percent			20	45	35	=	100

Log Stock Tables: In making end product appraisals, volume in each log grade must be segregated by diameter classes. Several methods have been devised.

1. The ratio method is a refinement of the method of obtaining grades illustrated above. The ratio values are further separated into diameter classes within the grade by the use of taper tables. These are totaled by log size groups and expressed as percentages of the sum of the woods net ratios. Volumes in each grade or diameter class are found by applying these percentages to the total volume.

2. In the frequency method, each tree is weighted by a frequency number. Frequency is the basal area factor divided by the basal area of the tree. Each log times its corresponding frequency is tallied into grade and diameter classes. The sum of the number of logs in each size class by grades is then converted to a volume basis. The result is a conventional log stock table by volume before application of overrun factors.

THE FREMONT METHOD OF LOG STOCK TABLE COMPILATION

The Fremont National Forest has devised a procedure for log stock table compilation with the variable plot method. The method is basically designed for hand compilation. The data is transformed from a variable plot status to an adjusted basis equivalent to plots occupied by a tree of average diameter for the cruise. The method and a sample is covered in detail in the appendix.

OTHER DATA

1. Stand table information may be computed using frequency numbers. Tree numbers by diameter classes result when the frequency number is multiplied by the number of trees in the class divided by the total number of measured plots. The cumulative frequency should be curved by diameters unless a very large sample is used.

2. Poles may be tallied using a small basal area factor and required frequency to determine number per acre.

3. Stand improvement information obtained on the sample points may be summarized in the usual manner.

4. Nonmerchantable snags may be tallied separately for the sampling points. The count should not be included with the merchantable tally. Average basal area per acre of snags can then be computed and used to get cost of snag falling.

STATISTICAL ANALYSIS: Sampling error using the variable plot method is made up of two components. Most of the sampling error is in the determination of the average basal area per acre. Since there is a close correlation between volume and basal area, the volume-basal area ratio usually has a small sampling error. In getting the sampling error of the total volume, the two components must be squared, added, and the square root extracted. A simple analysis consists of computing the sampling error of the sample point tally and expressing it as a percent of the mean.

Small numbers are involved making rapid calculations possible, and unless extreme variation in the ratios is encountered, the results should be satisfactory.

Statistical analysis of a variable plot cruise is covered on page 224 Dilworth's book. Briefly stated:

$$S.E.\% = \sqrt{(\text{S.E. of volume basal area ratio in \%})^2 + (\text{S.E. of tree count in \%})^2}$$

APPENDIX

	Part
Equipment List	a
The Plot Radius Factor Method of Determining Diameter at the 16-Foot Point on a Tree	b
Methods of Determining Form Class Using Variable Plot Cruising Techniques	c
Decimal C Board Foot-Basal Area Ratio Tables by Girard Form Classes for 16-Foot Logs. For form classes 67 to 90, inclusive	d
Board Foot-Basal Area Ratio Tables by Girard Form Classes (64,66, 68, 70, 72, 74, 76, 78, 80, and 84) for 32-Foot Logs	e
Volume Table for Determining Volume in 16-Foot Logs When Sighting at 16 Feet	f
Volume Table for Determining Volume in 32-Foot Logs When Sighting at 16 Feet	g
Cruise Calculation Sheet for Variable Plot Cruises	h
The Frequency Method of Log Grade and Log Stock Table Compilation	i
Bibliography	j

EQUIPMENT LIST

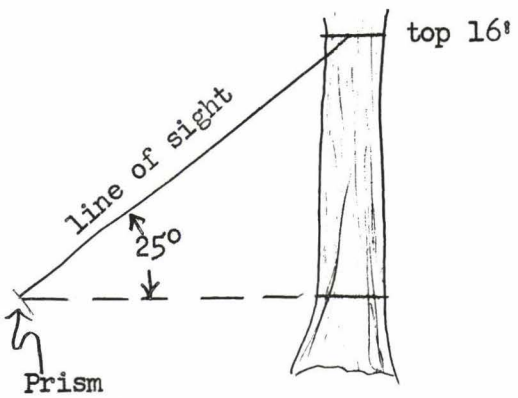
Suggested list of materials and equipment needed or useful for each cruising crew:

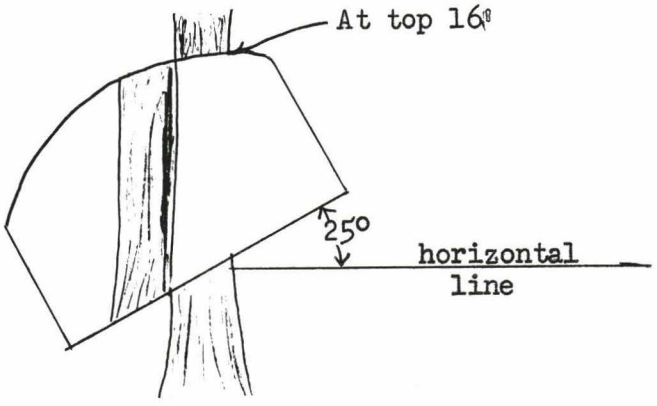
1. Prism, Spiegel-relaskop or similar variable plot method instrument.
2. Wedge prism level
3. Form factor slide rule
4. Variable plot tally cards
5. Aerial photos (with waterproof transparent covers)
6. Map
7. Grease pencils, lead pencils
8. Compass
9. Tatum holder
10. Diameter tape
11. Biltmore stick
12. Increment borer
13. Log grade instructions
14. Marking rules for area
15. Cruising ax
16. 100' steel roll tape and/or 2 chain trailer tape
17. Abney level
18. Redi-mapper
19. Hand level

THE PLOT RADIUS FACTOR METHOD OF DETERMINING DIAMETER AT 16-FOOT POINT ON A TREE

1. Hold the prism on a plane at right angles to the line of sight to the top of the 16-foot log.

2. Locate a position on the ground at which (with line of sight to 16 feet corrected to horizontal distance) the tree at the 16-foot point appears to be a borderline tree. The slope distance is corrected to horizontal by rotating the prism by exactly the same angle as the vertical angle of of the line of sight. This procedure has been previously covered.





3. Measure the horizontal distance from the sighting point to the center of the tree. Observations should be made on a contour at which the line of sight to d.b.h. is horizontal. If horizontal measurement to the tree can not be made, other slope adjustments are required.

4. This horizontal distance divided by the plot radius factor gives the diameter o.b. at top of 16-foot log.

$$PRF = \frac{43{,}560 - B.A.F.}{4\ B.A.F.} * 12$$

or $\frac{d}{12w}$ where d is the horizontal distance to the tree in feet and w is the diameter of the tree in feet. Multiplying by 12 converts w to diameter in inches. The plot radius factor is the distance from the tree in feet for each inch of diameter, when the point observed is displaced its exact width. Diameter then becomes:

$$\text{Diameter o.b. (w) in inches} = \frac{\text{horizontal distance.}}{PRF}$$

For a given basal area factor distances for each inch of diameter can be compiled in tabular form for convenience in use.

5. To reduce the o.b. diameter at top of 16 feet to i.b. it is necessary to apply a bark thickness ratio. This may be done in the office.

A pending employee suggestion by Don Tandy of the Snoqualmie N.F., covers a simple aid for application of the above procedure when using prisms ground to exact factors of 10,20,25,30, or 40. The next page is a copy of the suggestion.

APPLICATION OF THE PLOT RADIUS FACTOR METHOD OF DETERMINING TREE DIAMETER AT THE 16-FOOT POINT WHEN USING PRISMS GROUND TO FACTORS OF 10, 20, 25, 30, OR 40.

The cruising procedures of the variable plot cruising system can be simplified by eliminating the D.B.H. and form class measurements and using the top of the first sixteen-foot log as the sighting point. Employing the plot radius factor of prisms with basal area factors of 10, 20, 25, 30 and 40 the following table has been constructed. With the prism indicated the diameter of the tree at the sixteen-foot level can be determined by measuring the horizontal distance from the point where the sixteen-foot level is exactly subtended to the center of the tree at D.B.H. This diameter when reduced by the bark thickness can be used for volume calculations, utilizing volume tables previously constructed. This method of measurement saves time by eliminating D.B.H. measurements and improves accuracy by eliminating form class estimates.

The table can be attached to the tatum for ready reference.

PRISM DOB at 16'-Distance Equivalents

	Distance (Ft.)				
Dia	BAF10	BAF20	BAF25	BAF30	BAF40
6	16.5	11.7	10.5	9.5	8.3
8	22.0	15.6	13.9	12.7	11.0
10	27.5	19.5	17.4	15.9	13.8
12	33.0	23.4	20.9	19.1	16.5
14	38.5	27.2	24.4	22.2	19.3
16	44.0	31.1	27.9	25.4	22.0
18	49.5	35.0	31.4	28.6	24.8
20	55.0	38.9	34.9	31.8	27.5
22	60.5	42.8	38.3	34.9	30.3
24	66.0	46.7	41.8	38.1	33.0
26	71.6	50.6	45.3	41.3	35.8
28	77.1	54.5	48.8	44.5	38.5
30	82.6	58.4	52.3	47.6	41.3
32	88.1	62.3	55.8	50.8	44.0
34	93.6	66.2	59.3	54.0	46.8
36	99.1	70.1	62.7	57.2	49.5
38	104.6	73.9	66.2	60.3	52.3
40	110.1	77.8	69.7	63.5	55.0
42	115.6	81.7	73.2	66.7	57.8
44	121.1	85.6	76.7	69.9	60.5
46	126.6	89.5	80.2	73.0	63.3
48	132.1	93.4	83.7	76.2	66.1
50	137.6	97.3	87.2	79.4	68.8

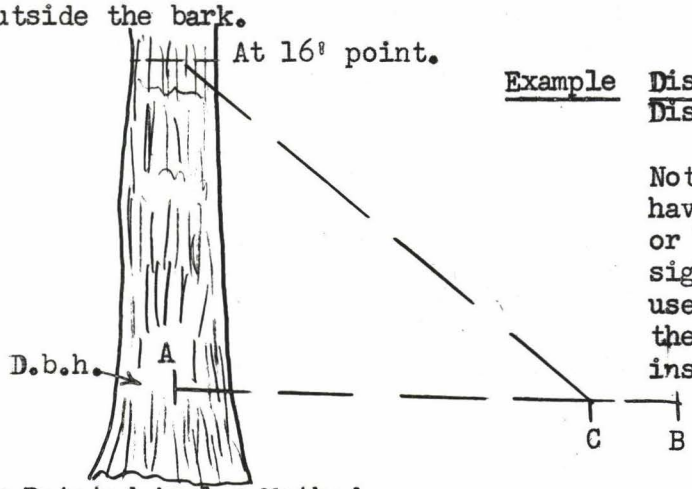
METHODS OF DETERMINING FORM CLASS USING VARIABLE PLOT CRUISING TECHNIQUES.

Form classes may be obtained by use of one of the following methods:

a. Proportionate Distance Method.

Locate points on the ground at which (with correction made for slope distance) the tree appears as a borderline tree at d.b.h. and at top of 16 feet.

The relation of these two distances indicates the form class outside the bark.



Example $\frac{\text{Distance AC}}{\text{Distance AB}}$ = form class o.b.

Note: Distances in each case have been corrected for slope or vertical angle of line of sight. This method may be used with the prism or any of the other angle projecting instruments.

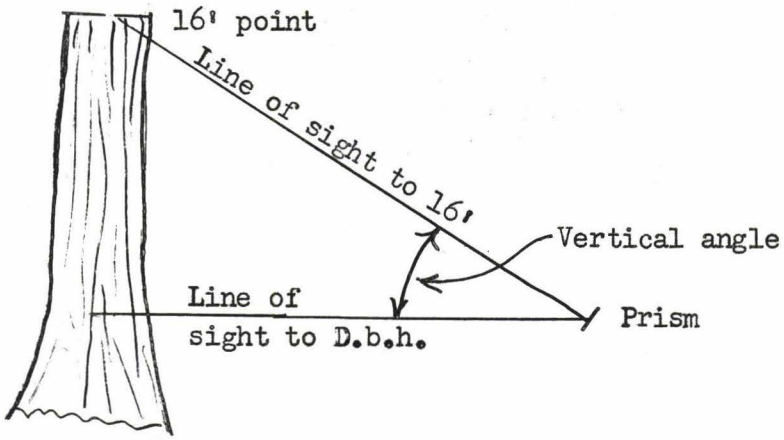
b. By Rotated Angles Method.

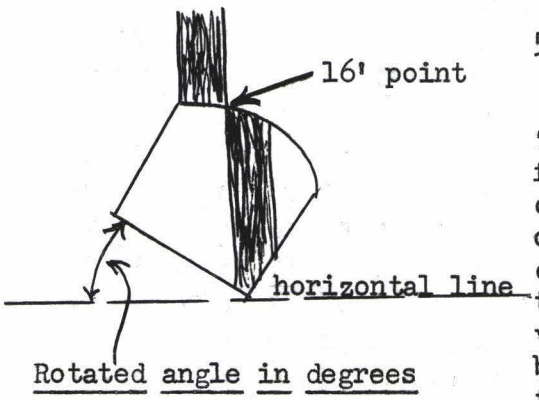
This method requires use of the prism.

The steps in determining form class by use of rotated angles are as follows:

1. Determine corrected distance at which the tree is a borderline tree at d.b.h.

2. From this point determine the vertical angle to d.o.b. at top of 16' log.





3. Remaining at same point sight at top of 16-foot point and rotate the prism around the line of sight until the tree appears as a borderline tree.

4. $\frac{\text{Cosine rotated angle}}{\text{Cosine vertical angle}}$ = form class o.b.

5. Form class o.b. times bark thickness ratio equals form class inside bark.

The attached timber survey aid is designed for use with prisms in determining form class inside bark. On the form the indicated form classes outside of the bark were calculated by the division of the cosine of the rotated angle by the cosine of the vertical angle. Form classes inside the bark at the bottom of the form are obtained from the application of the bark thickness ratio.

The two blank tabular blocks on the back of the aid are a convenient device for recording computed plot radius distance for trees of various diameters after the plot radius factor is determined. The table will accommodate trees up to 69 inches in diameter but may be made for any range of sizes. This device saves numerous field calculations and greatly reduces the possibility of errors. The form provides space for data on two prisms.

The described methods may be similarly used for determining form class at the 32-foot or other point on a tree.

FRONT

FORM CLASS - Outside Bark

Rotated Angle

Vertical Angle	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
2	100	100	100	100	98	98	97	96	95	94	93	91	90	88	87	85	83	81	79	77	74	72
4		100	100	99	99	98	97	96	95	94	93	92	90	89	87	85	83	81	79	77	74	72
6			100	100	99	98	98	97	96	94	93	92	90	89	87	85	83	81	79	77	75	72
8				100	99	99	98	97	96	95	94	92	91	89	87	86	84	82	80	77	75	73
10					100	99	98	98	97	95	94	93	91	90	88	86	84	82	80	78	75	73
12						100	99	98	97	96	95	93	92	90	89	87	85	83	81	78	76	74
14							100	99	98	97	96	94	93	91	89	87	85	83	81	79	77	74
16								100	99	98	96	95	94	92	90	88	86	84	82	80	77	75
18									100	99	97	96	95	93	91	89	87	85	83	81	78	76
20										100	99	97	96	94	92	90	88	86	84	82	79	77
22											100	99	97	95	93	91	89	87	85	83	80	78
24												100	98	97	95	93	91	89	86	84	81	79
26													100	98	97	96	92	90	88	85	83	80
28														100	98	96	94	92	89	87	84	81
30															100	98	96	93	91	88	86	83
32																100	97	95	93	90	88	85
34																	100	98	95	92	90	87
36																		100	97	95	92	89
38																			100	97	94	91
40																				100	97	94
42																					100	97
44																						100

FORM CLASS - I.B.

Form Class - O.B.

Bark Thickness Ratios	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
95	68	70	72	74	76	78	80	82	84	86	87	89	91	93	95
94	86	70	71	73	75	77	79	81	83	85	86	88	90	92	94
93	67	79	71	73	74	76	78	80	82	84	86	87	89	91	93
92	66	68	70	72	74	75	77	79	81	83	85	86	88	90	92
91	66	67	69	71	73	75	76	78	80	82	84	86	87	89	91
90	65	67	68	70	72	74	76	77	79	81	83	85	86	88	90
89		66	68	69	71	73	75	77	78	80	82	84	85	87	89
88		65	67	69	70	72	74	76	77	79	81	83	84	86	88
87			66	68	70	71	73	75	77	78	80	82	84	85	87
86			65	67	69	71	72	74	76	77	79	81	83	84	86
85			65	66	68	70	71	73	75	77	78	80	82	83	85
84				66	67	69	71	72	74	76	77	79	81	82	84
83				65	66	68	70	71	73	75	76	78	80	81	83
82					66	67	69	71	72	74	75	77	79	80	82
81					65	66	68	70	71	73	75	76	78	79	81
80						66	67	69	70	72	74	75	77	78	80

Aid for computing form class by the rotated angles method.

Appendix - Part c

BACK

PLOT RADIUS FACTOR AID

For a _____ Diopter Prism Having a Basal Area Factor _____ and a Plot Radius Factor of _____ feet per inch diameter.

Diameters in Inches

	0	1	2	3	4	5	6	7	8	9
10										
20										
30										
40										
50										
60										

For a _____ Diopter Prism Having a Basal Area Factor _____ and a Plot Radius Factor of _____ feet per inch diameter.

	0	1	2	3	4	5	6	7	8	9
10										
20										
30										
40										
50										
60										

Cosines of slope

2° - .999	14° - .970	26° - .899	38° - .788
4° - .998	16° - .961	28° - .883	40° - .766
6° - .994	18° - .951	30° - .866	42° - .743
8° - .990	20° - .940	32° - .848	44° - .719
10° - .985	22° - .927	34° - .829	
12° - .978	24° - .914	36° - .809	

$$\text{Slope Distance} = \frac{\text{Horizontal Distance}}{\text{Cosine Slope in Degrees}}$$

Decimal C Board Foot-Basal Area Ratio Tables by Girard Form Classes for 16-Foot Logs.

For form classes 67 to 90, inclusive,

Compiled by Leo D. Caron

These are available on request from the regional office for official use.

Appendix - Part d

Board Foot-Basal Area Ratio Tables by Girard Form Classes

(64, 66, 68, 70, 72, 74, 76, 78, 80, and 84)
for 32-Foot Logs.

Compiled by personnel of the Gifford Pinchot
National Forest.

These are available on request from the regional office for official use.

VOLUME TABLE FOR DETERMINING VOLUME IN 16-FOOT LOGS WHEN SIGHTING AT 16-FEET

Volume in Scribner Decimal C Per Square Foot of Stem Area Inside Bark at 16' 1/

Dib	Merchantable Height - 16 Foot Logs										
16'	1	2	3	4	5	6	7	8	9	10	11
10	11										
12	11	15	23								
14	10	14	22	30							
16	11	14	21	29	36						
18		15	23	30	38	46					
20			23	31	38	47	55	63			
22				32	40	48	57	65	73		
24				32	40	49	57	65	73		
26				34	42	51	60	68	77		
28				33	41	50	58	66	75		
30				34	43	52	60	69	78		
32				34	42	51	59	68	76		
34				35	44	52	61	70	79	88	
36				34	43	51	60	69	77	86	
38					43	52	60	69	78	86	
40					43	52	61	69	78	87	95
44					44	52	61	70	79	87	97
48					44	53	62	71	79	88	97
54					44	53	62	71	80	89	98
60						54	63	72	81	90	99
66						54	63	72	81	90	99

1/ Basic volumes derived from Form Class Tables for 16-foot logs by Mason, Bruce and Girard. Merchantable top di.i.b. considered to be equal to 40 per cent of D.B.H. with a minimum of eight inches.

VOLUME TABLE FOR DETERMINING VOLUME IN 32-FOOT LOGS WHEN SIGHTING AT 16-FEET

PROPORTIONAL PLOT - VOLUME SUMMARY SHEET
32 FOOT LOG SCALE - SCHIBNER

T.___ R.___ Sec._____ Subdiv._____ Acres___ Plots____

VOLUME IN BOARD FEET PER SQUARE FOOT OF STEM AREA IB AT 16'

DIB	UTILIZATION HEIGHT - 32' LOGS											TOTAL BY SPECIES		
16'	1	1½	2'	2½	3	3½	4'	4½	5	5½	6			
9	81													
10	79	174	176											
12	76	162	202	275	349									
14	74	146	218	297	377									
16	73	153	233	314	396	475	555							
18	76	159	242	326	411	493	576							
20	77	163	249	336	423	507	592	674						
22	78	166	255	344	433	518	604	688						
24	80	170	260	350	441	528	615	701						
26	82	173	264	355	447	535	624	711						
28	84	176	268	360	453	542	631	720	808					
30	86	178	271	364	457	547	638	727	817	906	996			
32			273	367	461	552	644	734	824	914	1004			
34			275	370	465	556	648	739	830	921	1012			
36			277	372	468	560	653	744	836	927	1018			
38			279	375	471	563	656	748	841	932	1024			
40			281	377	473	566	660	752	845	937	1030			
44				382	478	572	666	759	852	945	1039			
50				387	483	578	672	766	861	955	1049			
60				383	488	585	681	777	873	967	1062			
70				387	493	590	687	783	879	975	1071			

No. of Trees				Basal Area		Volumes		Total Ratio
Species	No.	Plot Ave.	X Prism Factor	X Wood to Bark ratio squared	=BA IB per acre sq.ft.	X Average Ratio = Bd.Ft.per acre Gross	Net	Total No.Trees / Ave.Ratio in Board Feet

Data computed by Mason, Bruce and Girard, Consulting Foresters.

CRUISE CALCULATION SHEET FOR VARIABLE PLOT CRUISES

The following volume calculation sheet for variable plot cruises is advantageous for these reasons:

1. It is suitable for both east side and west side cruises.
2. It is applicable for cruises sighting at d.b.h. or at 16 feet.
3. It furnishes an estimated number of trees per sampling unit which is helpful as a guide in marking out east side sales.
4. It furnishes additional information which may be useful, such as average tree size and volume and several items pertinent to the cruise.
5. The form is self-explanatory.
6. Items not pertinent to a cruise need not be filled out.

Quality Adjustment Sheet for Variable Plot Cruises

The attached sheet adjusts the cruise data from the variable plot status to a condition where all trees are adjusted to a common area sample basis. The common area to which all data is adjusted is the plot which would be represented by a tree of average diameter.

The following explanation covers the items as numbered on the adjustment sheet:

1. Basal area factor = square feet of basal area per acre.
2. Average diameter - this would be at d.b.h. or at 16 feet depending on where the tree is sighted. The calculation for this is shown at the bottom of this page.
3. Number of quality samples taken - no explanation needed.
4. Acres sampled = average area sampled times the number of samples.
5. Plot size in acres = determined for average tree diameter.
6. Tree diameter = at d.b.h. or 16 feet (where sighted).
7. Basal area or stem area = no explanation needed.
8. Trees per square foot of basal or stem area = no explanation needed.
9. Multiplication factor - the exact basal area for the average diameter as determined for item two multiplied by the trees per square foot of basal area for each diameter class.
10. Log tally = all logs of a given log grade are tallied opposite the tree diameter in which they occur.
11. Adjusted logs = the logs are adjusted from the variable plot status to a common area status by multiplying by the adjustment factor.
12. Logs by diameter classes = enter the diameter classes in the circles.

Adjusted logs as totaled by diameter class by log grades are entered on the log stock table.

To avoid confusion it is suggested that one log grade be worked out at a time. All trees containing a given log grade are tallied on one sheet along with all logs tallied for that log grade in those trees.

Calculation of Avg. D.B.H.
No. Samples B.A.F.
(4) * (5) = Avg. B.A./Tree to get dia.

Tree Diam.	No. Trees	Avg./Point	B.A./Acre (4)	Trees/Sq.Ft. Basal Area	Trees/Acre (5)
12					
14					
16					
18					
20					
22					
24					
26					
28					
30					
32					
34					
36					
38					
40					
42					
44					
46					
48					
50					
52					
54					
56					
58					
60					
62					
64					
66					
68					
70					
72					
Total					

S-SALES_____ _____Diopter Prism _____Basal Area Factor (1) _____Ave. Diam. (2)

_____Sale _____Quality Samples Taken (3) _____Acres sampled (4) _____Plot size in acres (5)

Grade_____Logs Sp._____

LOGS BY DIAMETER CLASSES (12)

Tree Diam. (6)	Tree Basal or Stem Area (7)	Trees per square foot of stem area (8)	Multiplication Factor (9)	(10) Log Tally	(11) Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs	Log Tally	Adj. Logs
12	.79	1.274																											
14	1.07	.935																											
16	1.40	.716																											
18	1.77	.566																											
20	2.18	.458																											
22	2.64	.388																											
24	3.14	.318																											
26	3.69	.271																											
28	4.28	.234																											
30	4.91	.204																											
32	5.59	.179																											
34	6.30	.159																											
36	7.07	.141																											
38	7.88	.127																											
40	8.73	.115																											
42	9.62	.104																											
44	10.56	.095																											
46	11.54	.087																											
48	12.57	.080																											
50	13.64	.073																											
52	14.75	.068																											
54	15.90	.063																											
56	17.10	.058																											
58	18.35	.055																											
60	19.64	.051																											
62	20.97	.048																											
64	22.34	.045																											
66	23.76	.042																											
68	25.22	.040																											
70	26.73	.037																											
Totals																													

Note: Numbers in brackets are item number. For relation of one item to another see cover sheet.

CRUISE CALCULATION SHEET FOR VARIABLE PLOT CRUISES

S
SALES

Note: Circled numbers indicate item number. Other numbers in a block indicate relationship to other items.

_____ _____ Sale, Cutting Unit No._____

Number of sample points taken _____ (1)
Acreage of commercial timber type in unit (2) _____
Average form class by species for unit - P.P. _____, W.F._____, L.P._____, _____, _____
_____ Prism diopter. Basal area factor (3) _____, Plot radius factor _____
Bark thickness ratios (4) (I.B./O.B.) by species P.P._____, P.P._____, W.F._____, _____, _____, _____

SPECIES	TOTAL TALLY (5)	AVERAGE PER (POINT (5÷1) (6)	Basal Area Per Acre: O.B. at sighting point (6x3) (7*)	Basal Area Per Acre: I.B. (7x4) at 16' (8*)	AVERAGE RATIOS (bd.ft./sq.ft.) (9)	AVERAGE VOLUME PER ACRE (GROSS) M. bd.ft. (7 or 8) x9 (10)	PER CENT SOUND (100% less D. & B.) (11)	NET AVERAGE VOLUME PER ACRE NET(bd.ft.) (10 x 11) (12)	AVERAGE DIAMETERS (See cover sheet for quality calculations) (13)	AVERAGE BASAL AREA PER TREE (14)	AVERAGE NUMBER OF TREES PER ACRE (7 or 8 ÷ 14) (15)	ESTIMATED NUMBER TREES ON AREA (15 x 2 (16)	NET VOLUME PER TREE (12 ÷ 15) (17)	NET VOLUME ON AREA 16 x 17 or 12 x 2
P.P.														
W.F.														
L.P.														

* Use 7 when sighting at d.b.h., 8 when sighting at 16'.

Appendix Part h

THE FREQUENCY METHOD OF LOG GRADE AND LOG STOCK TABLE COMPILATION

In variable plot cruising when the total volumes of trees intercepted by the angle are used for compiling log grades by log size classes, it is necessary to reduce the various tree sizes and the logs in these trees to a common area basis. In the previously described method, use of volume-basal area ratios accomplishes this automatically.

The reduction may be to any size of area such as a per acre basis, an area equivalent to the area actually sample, or other desired area basis.

In this method graded logs occur in the same frequency as the trees in which they occur.

The following quality adustment instructions and form is designed for hand calculation and adjusts the quality taken to an area equivalent to the area actually sampled for quality. This procedure was devised by the Fremont National Forest.

One quality sheet is required for each log grade.

BIBLIOGRAPHY:

1. Afanasiev, M. The Bitterlich Method of Cruising - - Why Does it Work? Jour. Forestry 55: 216-217. 1957.

2. John F. and Lucien B. Alexander. Application of the Variable Plot Method of Sampling Forest Stands. Oregon State Board of Forestry-Research Note. No. 30, February, 1957.

3. Bruce, David. A New Way to Look at Trees. Jour. Forestry 53:(3):163-167 March, 1955.

4. Dilworth, J.R. Log Scaling and Timber Cruising. O.S.C. Cooperative Association, Revised 1957.

5. Grosenbaugh, L.R. Plotless Timber Estimates - - New, Fast, Easy. Jour. Forestry 50:(1); 32-37.

6. Marsh, Norman. Prism Cruising Method Adopted. Oregon State Tax Commission, Valuation Division Bulletin 6-56:6-9. June 30, 1956.

7. Morrow, R.R. Computation of Volume in the Bitterlich Method of Cruising. Jour. Forestry. January, 1958.

8. Trappe, James M. Experience with Basal Area Estimation by Prisms in Lodgepole Pine. PNWFES Research Note No. 145. April, 1957.